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ENERGY HARVESTING – OPPORTUNITY FOR FUTURE REMOTE APPLICATIONS

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Abstract: *This paper deals with energy harvesting principles, current and future applications of these devices. The paper critically evaluates opportunity of such power supplies for future remote applications (wireless sensing, autonomous electronics, mobile technologies etc.) and makes an effort to describe advantages of energy harvesters against traditional power supplies. The definition of energy harvesting describes these technologies as the use of an ambient energy to provide electrical power for small electronic and electrical devices making them self-sufficient. The technologies employed variously convert human power, body fluids, heat differences, vibration or other movement, ultraviolet, visible light or infrared to electricity and there are more options coming along. The progress in wireless technologies on start of new millennium made demands on inexhaustible power source for wireless applications and the ambient energy seems like the suitable power source. The surrounding of most engineering systems contains some form of an ambient energy. Currently most of energy harvesting applications is tested in the laboratory and practical applications of some energy harvesting technologies (photovoltaic, thermoelectric generators, vibration energy harvesters etc.) have been used in several engineering applications. The aim of this paper is brief state of art and review of these technologies.*

Keywords: ***Energy harvesting, mechatronics, generator, electro-mechanical system.***

1. Introduction

This paper deals with energy harvesting principles, current and future applications of these devices. Energy harvesting technologies have emerged as a prominent research area and it continue to grow at rapid pace (Belleville et al., 2010). A wide range of applications are targeted for the harvesters, including wireless sensor nodes for structural health monitoring, embedded and implanted sensor nodes for medical applications, monitoring of mechatronic systems (e.g. tire pressure in automobiles), recharging the batteries of large systems or running security systems in household conditions (Poulin et al., 2004; Paradiso and Starner, 2005). Recent development includes the components and devices at micro–macro scales covering materials, electrodynamic (thermal, solar etc.) conversion systems, electronics, and integration. The growing demand for energy harvesting systems (Niyato et al., 2007) has motivated this paper to present the current state of art in this field.

Definition of energy harvesting system (Mateu and Moll, 2005)**:** An energy harvesting device generates electric energy from its surroundings using some energy conversion method. Therefore, the energy harvesting devices here considered do not consume any fuel or substance. On the other hand the environment energy levels are very low (at least for today's electronic devices requirements).

2. Development in Energy Harvesting Field

The current electronic circuits and applications are capable to operate at microwatt power levels (Chao et al., 2007; Vullers et al., 2009) and it is feasible to power them from non-traditional energy sources. This leads to use energy harvesting technologies, which provide power to charge, supplement or replace batteries in systems where battery use is inconvenient, impractical, expensive or dangerous (Mateu and Moll, 2005). Power requirements of small electronic products including Wireless Sensor

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Networks (Niyato et al., 2007) and GSM mobile phones and types of employed batteries are shown in Fig. 1 (www.idtechex.com). Energy harvesting technologies compete with other traditional sources of electricity for small electronics, Wireless Sensor Networks and electrical devices. The lifetime of electronic devices is guaranteed up to ten years but the lifetime of their batteries is typically only a few years. The energy harvesting technologies can provide alternative energy source for these electronics.

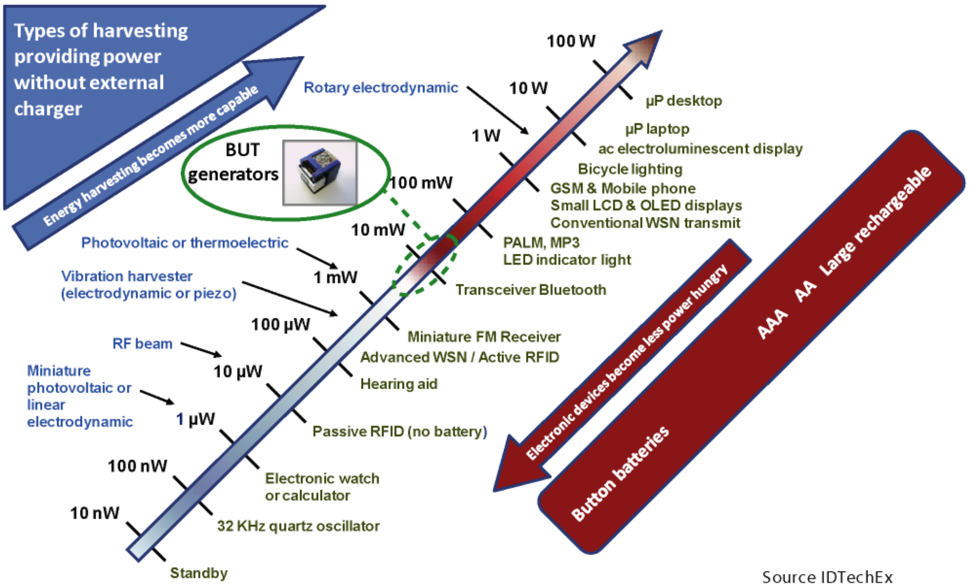

Fig. 1: Power requirements of electronics and power of energy harvesting products (www.idtechex.com) with shown Brno University of Technology vibration power generators.

3. Potential Energy Harvesting Applications

The review of energy harvesting applications is shown in Tab. 1. The investigation of self-powered systems (James, et al., 2004) depends on physical principle of electro-mechanical, ambient conditions and used application.

Tab. 1: Review of energy harvesting applications.

Sources of energy	**Energy Harvesting Systems**	**Applications**
Solar energy	- Photovoltaic cells	- Remote electronics, etc.
Thermal gradient	- TEG - Thermoelectric generators (Seebeck effect)	- Aeronautic/automotive industry, etc. - Human body heat (e.g. watches) - Frictions
Human body movement	- Passive	- Health monitoring (e.g. pacemaker, earpiece)
	- Active (walking, typing, etc.)	- Source for portable devices (army) - Source for MP3, mobile phones …
Random movement	- Random oscillation	- Generator inside tires
	- Random load, shocks	- Generator for traffic monitoring
	- Fluid flow, etc.	- Piezo strips (eel) generators
Vibrations	- Resonance system	- Electro-static generators - MEMS
		- Piezo-electric generators
		- Electro-magnetic generators

The energy harvesting technologies can be useful in aeronautic and automotive applications, as source for portable devices and source for wireless sensor networks for intelligent monitoring and diagnostic of mechatronic systems. So far, the majority of work on energy harvesting development has been concerned with photovoltaics (Nasiri et al., 2009). Most of these applications have benefitted from huge investment in photovoltaics as renewable energy of which energy harvesting i.e. power for small devices, is a minor part. Further energy harvesting devices employ variously converting of human power, body fluids, heat differences, vibration or other random movement. The surrounding of most engineering systems contains some form of such ambient energy.

The development in field energy harvesting from vibration started on the end of previous millennium (Williams and Yates, 1996). The energy harvesting field can be divided into micro and macro scale devices. The micro scale energy harvesting technologies (Peano and Tambosso, 2005; Liu et al., 2008) include development of micromechanical electromagnetic systems (MEMS), SMART materials (Guyomar et al., 2005) and nanotechnologies (smart dust or embedded battery-less sensors) (Vijayaraghavan and Rajamani, 2010). The development of macro scale energy harvesting systems is focused on sources for wireless sensor networks (Gungor and Hancke, 2009) and remote electronics with power consumption several miliwatts.

4. Energy Harvesting at Brno University of Technology

The energy harvesting development of our team has started in 2004 and it is focused on macro scale energy harvesting from mechanical energy of vibrations (Hadas et al., 2007). Several vibration power generators were developed for powering of wireless sensors for aeronautic application (Hadas et al., 2008). Our development is focused on energy harvesting from very low level of vibrations in engineering applications (Hadas et al., 2010). The improved generator operates correctly in 0.1 g level of vibrations and with operating frequency 17-18 Hz and output power 7 mW (5 V). The harvested output power (voltage) grows with level of vibrations. The measurement of this generator is shown in Fig. 2. The picture of this very sensitive BUT generator is included in Fig. 1. It demonstrates potential applications of this technology and our development as source for industrial wireless sensors in a modern diagnostic system. The very sensitive generator presents opportunity for energy harvesting from random movement too.

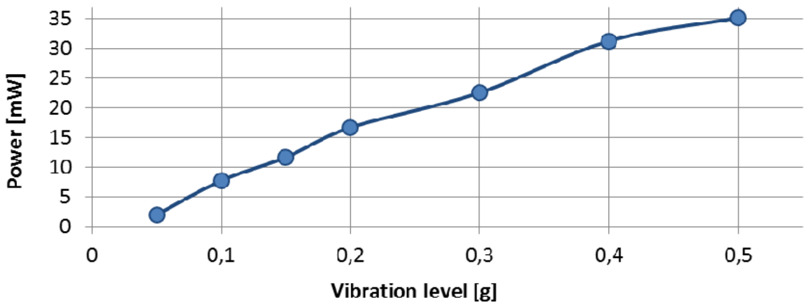

Fig. 2: Measurement of BUT generator, harvested power vs. vibration level.

5. Successful Energy Harvesting Applications

Currently, the most of energy harvesting applications is tested in the laboratory and practical applications of some energy harvesting technologies have been used in several engineering applications. Main players in energy harvesting fields are companies: AdaptivEnergy, EnOcean, Holst Centre, Lumedyne, MEMS@Mit, Micropelt, Microstrain, Morgan Electro Ceramics, Piezo TAG, Perpetuum, Thermo Life, TPL Micropower, Transense Technology, Visityre. In total, there are about 500 organizations working on energy harvesting and about half of them being academic.

There is already a large number of successful energy harvesting applications, particularly those using technology harvesting electricity from light, human movement and heat. Photovoltaic conversion of light is the most popular, being used from road furniture to satellites, with solar powered phones, torches, lanterns, radios, wristwatches and other devices increasingly seen. Partly, this is because photovoltaic has no moving parts and is therefore unusually long lived and reliable and partly it delivers high power per unit of volume and is rapidly improving in affordability, size, weight, spectral response and other parameters. No other forms of energy harvesting has all these credentials but alternatively are also needed because a high proportion of devices using energy harvesting will be embedded in future, where light is not available.

6. Conclusions

Energy harvesting has been successful in several engineering (aeronautic, automotive, military and civil engineering). The first really high volume of industrial applications is wireless sensor networks which are rising to at least billions of devices per year. Other consumer goods such as mobile phones and laptops will become significant; however, generated power of energy harvesting devices is very low for these consumer goods. Energy harvesting technologies are enabling the commercial progress of next-generation ultra-low-power electronic devices and systems. These devices are being deployed for wireless as well as wired systems such as mesh networks, sensor and control systems, micro-electro-mechanical systems (MEMS), radio frequency identification (RFID) devices, and so on.

The aim of this paper was briefly reviewed energy harvesting technologies and their opportunity for future wireless and remote applications.

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